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DEVELOPMENTS IN DAIRY WASTE DISPOSAL

Nandor Porges
Eastern Regional Research Laboratory
Eastern Utilization Research and Development Division
Agricultural Research Service
U.S. Department of Agriculture
Philadelphia 18, Pennsylvania

Every milk handling plant is faced with the necessity of disposing dairy waste water. Something must be done with this waste, and the ideas developed in the course of our research will be of value to dairy engineers and plant personnel in solving problems in waste disposal. Such disposal may be direct without prior treatment, and the simplest way is by a public sewer system; but excellent housekeeping must be practiced to keep the sewage service charges as low as possible. Another way is by sub-surface tile fields about which we have little information, if any, as related to dairy wastes. Spray irrigation is practiced in some regions, and a current cooperative study between our Laboratory and the University of Wisconsin is supplying some interesting information.

On the other hand, waste treatment is necessary, if direct waste facilities are not available. The development of a satisfactory method of treatment is based on an understanding of the biological processes involved in converting this liquid waste to harmless or disposable materials. Our investigations centered for the past few years on the biochemical oxidation of dairy wastes (9,10). The laboratory studies were translated to pilot plant investigations treating 10,000 gallons of waste daily in a cooperative study with the Pennsylvania State University (6). Theories and ideas developed in the course of these studies are meeting acceptance. We are told that over 60 dairy waste treatment plants have successfully applied these principles. Some handle as little as 2,000 gallons while others treat 150,000 gallons of waste daily, by means of a one tank fill-and-draw system or a continuous flow system.

DAIRY WASTE

The waste water from dairy plants is the liquid discharge containing milk solids washed from equipment, milk lost by occasional spillage and leakage, and whey and other discarded items. Losses may be kept as low as 1% of the milk received, when such milk is handled under stringent conditions. Unfortunely, losses are usually much higher, reaching the equivalent of as much as 3% for the small market milk dairy (8).

Water usage will generally be about equal to or greater than the weight of milk received. Thus, between 100 and 200 gallons of water are used for each 1,000 lb. of milk. Guides are available showing the amount and strength of waste produced by different types of milk-handling plants; a cottage cheese plant has 16 lb. of BOD, while a bottling plant has 8 lb. of BOD per 10,000 lb. of milk handled (11, 12).

POLLUTION EFFECT OF WASTE

These milk plant wastes are considerably stronger than equal volumes of municipal wastes, often having a polluting effect eight or more times greater than ordinary sewage. Thus, customary waste disposal facilities are not able to cope with this strong industrial waste. Some understanding of the concern of water pollution authorities may be obtained from the following.

A plant handling 50,000 lb. of milk daily loses 500 lb. of milk containing 50 lb. of solids. (These are low values). About 60 lb. of oxygen are needed to completely oxidize the waste. Since only about 8 lb. of oxygen are dissolved in a million lb. of water, the complete oxidation of this amount of waste will require the oxygen in 7.5 million lb. of water or 900,000 gallons. In other words, the waste from this dairy would deplete the oxygen in a pond 6 feet deep, 100 feet wide and 200 feet long. If the oxygen can not be replenished, anaerobic conditions persist with the production of disagreeable odors and the death of normal water life associated with well aerated clean water.

The strength of a waste is usually reported in parts per million (ppm) of 5 day BOD at 20° C. This is the biochemical oxygen demand or the weight of oxygen used under carefully standardized test conditions by a quantity of bacteria in the presence of the waste organic matter in that period of time. This 5 day BOD is calculated to be 67% of the ultimate BOD. In our investigations, we use a rapid chemical oxygen demand or COD test that gives results practically equal to the ultimate BOD (10). This COD test has been of great value in our work and is finding extensive use in many dairies to determine process losses as well as the pollution load of wastes.

AERATION STUDIES

Many of our studies were conducted in an aerator originally designed for the growth of yeast, and no difficulty was encountered when treating a simulated dairy waste containing 1,000 ppm solids and having 1,050 ppm COD (4). A solids balance on a continuous feed showed that all of the protein was recovered, while 44 units of the 53 units of lactose in the original waste were destroyed. In general, about 50% of the waste had disappeared, while 50% was taken up by the sludge. At that time, a single tank continuous treatment was proposed with continuous sludge removal by centrifugation. Roughly, this change from solubles to removable solids may be expressed:

$$\text{100 milk soluble solids} + \text{air sludge} \xrightarrow{\text{bacteria}} \text{50 bacterial cells} + CO_2 + H_2O \quad (1)$$

The large quantity of air used by the aerator was objectionable to the sanitary engineers. Respirometer studies were then made to determine the actual amounts of oxygen needed for the treatment of diary waste as well as its rate of utilization (1,3). The following interesting information was obtained when 500 ppm of sludge grew upon 1,000 ppm of skim milk, 500 ppm of lactose or 350 ppm of casein; the latter two present in the quantities found in skim milk. The action on skim milk was practically complete in 6 hours (Figure 1). The oxygen consumed was equal to about 37.5% of the complete oxygen demand. Lactose and protein were equally usable. The amount of oxygen used by skim milk was equal to the sum of the amounts used by i ingredients. The CO_2 evolved was equivalent to the O_2 used and practically all COD was removed from solution. Unfed cells also required oxygen. The following relationship was obtained:

$$\underset{(100\%\ \text{COD})}{\text{Milk organic matter}} + \text{oxygen} \longrightarrow \underset{(62.5\%\ \text{COD})}{\text{cells}} + CO_2 + H_2O \qquad (2)$$

A detailed consideration of the aeration process required a chemical analysis for the major elements in the sludge and the empirical formula, $C_5H_7NO_2$, gave a close approximation of the sludge cells (3). This gave a molecular weight of 113 for sludge cells and when corrected for 8.6% ash, was 124.

ASSIMILATION AND OXIDATION

Equations of assimilation and of endogenous respiration were established for the constituents of dairy waste based upon the chemical analyses and the data obtained from the respirometer studies.

Complete oxidation of lactose is represented:

$$C_{12}H_{22}O_{11}\cdot H_2O + 12O_2 \longrightarrow 12CO_2 + 12H_2O \qquad (3)$$

or in terms of the hypothetical monomeric unit for lactose:

$$(CH_2O) + O_2 \longrightarrow CO_2 + H_2O \qquad (4)$$

The minimal equation in terms of monomeric units for forming cells from carbohydrate using ammonia as a source of nitrogen is expressed thus:

$$5(CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3H_2O \qquad (5)$$

However, the data showed that 3 "oxygen demands" or carbons were completely burned up, while 5 were incorporated into cells accounting in this way for the ratio 37.5% to 62.5% implicit in equation 2. An equation for the assimilation shows that 240 units of lactose produce 113 units of cell (ash-free) and is written:

$$8(CH_2O) + NH_3 + 3O_2 \longrightarrow C_5H_7NO_2 + 3CO_2 + 6H_2O \qquad (6)$$

Similarly, equations were developed for oxidation and assimilation of casein:

$$C_8H_{12}N_2O_3 + 8O_2 \longrightarrow 8CO_2 + 2NH_3 + 3H_2O \qquad (7)$$

$$C_8H_{12}N_2O_3 + 3O_2 \longrightarrow C_5H_7NO_2 + NH_3 + 3CO_2 + H_2O \qquad (8)$$

The two assimilation equations were totalled, since the amount of lactose and casein in skim milk approximates these proportions.

$$\begin{array}{lcll}
8(CH_2O) + NH_3 + 3O_2 & \longrightarrow & C_5H_7NO_2 + 3CO_2 + 6H_2O & (6) \\
C_8H_{12}N_2O_3 + 3O_2 & \longrightarrow & C_5H_7NO_2 + 3CO_2 + H_2O + NH_3 & (8) \\
\hline
8(CH_2O) + C_8H_{12}N_2O_3 + 6O_2 & \longrightarrow & 2C_5H_7NO_2 + 6CO_2 + 7H_2O & (9)
\end{array}$$

Cell material is also oxidized, but at a very slow rate, and this may proceed even during the assimilative phase of growth (2).

$$C_5H_7NO_2 + 5O_2 \longrightarrow 5CO_2 + NH_3 + 2H_2O \qquad (10)$$

A summary of the many experiments in which a single dose feeding of 1,000 ppm of waste solids was given in the presence of 500 ppm sludge solids is plotted in Figure 2 (9). There is a rapid loss of the added organic matter until after 6 hours only about 500 ppm remains. At the same time, oxygen utilization shows a sudden decrease. The milligrams of oxygen used per hour under such conditions are shown in the lower portion of the figure. Later experiments showed that in the presence of sufficient soluble wastes, the rate of oxygen utilization was practically proportional to the weight of sludge cells (3). That is, 1,000 ppm of cells consumed oxygen practically twice as rapidly as 500 ppm cells, and assimilation was completed in about 3 hours.

COMPILATION OF DATA

Let us now interpret the laboratory results on the basis of one lb. organic matter in the waste.

1. Complete combustion of 1 lb. of organic or volatile solids in dairy waste requires 1.2 lb. of oxygen to satisfy the COD.

2. During assimilation, 37.5% of the COD substances is completely oxidized and uses 0.45 lb. of oxygen.

3. Time required for assimilation of the soluble wastes is related to the cell or sludge concentration. The greater the sludge concentration, the less time required for assimilation; 1 unit of cells and 1 unit of waste require 3 hours, while 1 unit of cells and 2 units of waste need 6 hours.

4. Oxygen required per hour for assimilation depends on cell concentration and, hence, on time needed to complete assimilation. If assimilation of 1 lb. of organic matter is completed in 3 hours, 0.15 lb. of oxygen is needed per hour; if 6 hours are required, then 0.075 lb. is needed per hour.

5. New cell organic matter produced from the 1 lb. organic waste amounts to 0.53 lb.

6. The new cell matter uses 0.75 lb. of oxygen for complete combustion; that is 62.5% of the original COD.

7. Seed sludge cells also need oxygen for respiration; 1 lb. of sludge organic matter needs 1.46 lb. of oxygen for complete combustion.

8. Oxygen requirements of the sludge vary depending on age and other factors. If 1% oxidation occurs per hour, then 20% is oxidized per day and 1 lb. sludge organic matter will use 0.29 lb. of oxygen per day. If oxidation is 10% per day, 0.15 lb. of oxygen will be needed.

9. The rate of purification or removal of milk solubles is about 10 times greater than the rate of oxidation. This characteristic may be of value in producing clear effluent quickly and in the recovery of high cell weight for subsequent use as a feed supplement such as B_{12}.

PILOT PLANT AND AERATION

These laboratory findings were not readily accepted nor applied immediately to dairy waste treatment. It became obvious that verification and application was a problem in sanitary engineering. Hence, a cooperative contract was made with the Pennsylvania State University to conduct 10,000 gallon pilot plant studies under the supervision of the Professor of Sanitary Engineering, R, R. Kountz (6).

One major difficulty immediately encountered was the insufficiency of oxygen supplied by the aeration devices commonly used. Although about 60 cubic feet of air contains 1 lb. of oxygen, only about 1% of the oxygen in the air is dissolved when air is bubbled through a solution from a perforated pipe. Porous plates permitted solution of 2 to 5%, while some devices gave 10% oxygen transfer (7). A specific ejector was finally selected for the 10,000 gallon treatment unit. The waste solution was recycled through a Venturi type tube, while air was drawn in from the atmosphere through a pipe extending above the surface of the waste. Under designated conditions, 25% of the oxygen was transferred. If the air was applied at 6 lb. pressure, as much as 40% of the oxygen was put into solution. Turbine type equipment also gives high oxygen transfer efficiencies.

When this problem of oxygen supply was solved, a simple one tank fill-and-draw system of treating dairy was developed. Aeration was regulated so as to assure sufficient oxygen. Sludge was continually reused for seed. To the surprise of the engineers, treatment was readily accomplished, provided the conditions in the laboratory were met. Odor was absent, solubles were removed rapidly, sludge waste was minimized by proper aeration; and the process was practically automatic. General information on these studies is available (8).

DESIGN OF AN INDUSTRIAL UNIT

While the research was still in progress and incomplete, an opportunity to try this rapid bio-oxidation at a commercial dairy came about through Dr. David Levowitz of the New Jersey Dairy Laboratories. One of his clients had orders to cease stream pollution. A fill-and-draw-batch type treatment was put into operation to handle 25,000 gallons of waste, and high degrees of purification were reported (5). It would be of interest to follow the calculations for this installation.

The size of the treatment unit and the oxygen demand are first determined. Pilot plant studies showed that 1 lb. of cells occupied 0.8 cubic feet after 30 minutes settling. If the total amount of sludge is known, the clear liquid depth can be determined and the aeration tank can be sized.

The dairy plant lost an estimated 300 lb. of milk solids daily (2.5% loss), which may be converted to about 150 lb. of new sludge cell material according to equation 1. Under ideal conditions, a balance is obtainable that does not favor sludge build-up, in which the 150 lb. of new cells replace 150 lb. of old sludge. It may be recalled that as much as 20% of sludge may be oxidized per day. If so, the 150 lb. of sludge oxidized represents 750 lb. of original sludge cells carried in the aerator. These cells will occupy 750 x 0.8 or 600 cubic feet when settled. Allowing one foot of freeboard to avoid entrainment when draining, the sedimentation portion was 1,200 cubic feet. To this was added 3,330 cubic feet, the volume of 25,000 gallons of waste. The tank then held 4,530 cubic feet or 34,000 gallons, with a drain at the 9,000 gallon level.

The oxygen requirements were also determined from the amounts required for assimilation and for endogenous respiration. The hourly loss over an 8 hour day was 300/8 or 37.5 lb. of milk solids. The oxygen required for assimilation was 37.5 lb. x 1.2 x 37.5% equaling 16.9 lb. per hour (Equation 9). Oxygen required to oxidize 150 lb. of sludge by endogenous respiration was 150 lb. x 1.46 x 1/24 or 9.2 lb. per hour (Equation 10). Total oxygen needed, therefore, during the 8 hours of waste flow became 16.9 + 9.2 or 26.1 lb. per hour.

When assimilation is completed, aeration is stopped and the cells are allowed to settle for 2 or 3 hours. The liquid is drained to the 9,000 gallon level and aeration may be continued at the lower rate of 9.2 lb. oxygen per hour until next morning. The cycle is repeated when the fresh waste is received by the treatment unit.

The quantities of air or the rate of aeration have not been mentioned, as they have little meaning except as a means of selecting desirable air dispersing device. The pilot plant study showed that a specific size ejector dissolved 1.6 lb. of oxygen per hour when the waste was recirculated at 60 gallons per minute. Thus, the 26.1 lb. of oxygen can be supplied by 17 ejectors, although 24 were installed to allow for excessive overloading and growth of the dairy.

The 25 HP, 900 gallon per minute pumps force the liquid from a header into two inch systems and through the ejectors, which draw in air through vertical pipes projecting above the surface of the liquid. During endogenous respiration, only one pump forces the liquid through all the jets, instead of 6 to 8 at the high rate. The disposal unit has been in practically automatic operation for almost three years. Figure 3 is a schematic presentation of such a treatment plant.

Selection of the type of aeration units depends upon the engineer. For example, ejectors are used for the continuous treatment of dairy waste at a large milk processing plant. In this case, when air is forced into the air intake under 6 lb. pressure, as much as 2.4 lb. oxygen is dissolved per jet in the liquid waste. Thus, the aeration part of a system can be decreased in size.

Another aerator that is reported to satisfy the oxygen requirement is one that permits the rapid recycling of the waste over a modified aeration tower. Regardless of the method used, whether compressed air, recycling of the waste through ejectors, filters or turbines, the calculated amounts of oxygen necessary for desirable microbial activity must be supplied to assure satisfactory treatment of dairy wastes.

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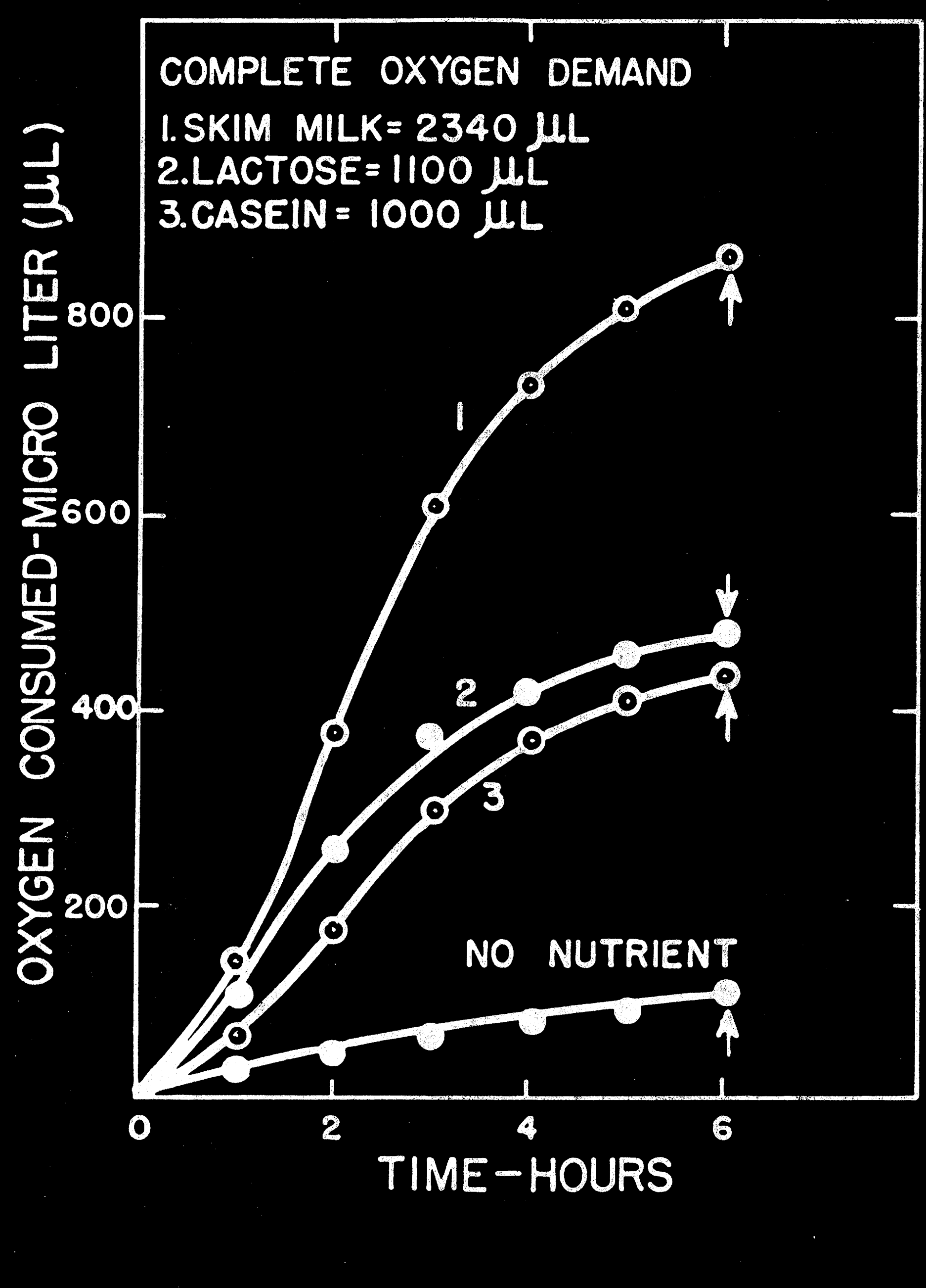
Figure 1. Oxygen consumed when 3 mg. skim milk or 1.5 mg. lactose or 1.05 mg. casein were aerated with 1.5 mg. sludge. About 37.5% of complete oxygen demand consumed during the assimilation.

Figure 2. Summary of aerating 1,000 ppm dairy waste with 500 ppm sludge, showing rapid decrease in organic waste and high rate of oxygen demand.

Figure 3. Schematic presentation of a fill-and-draw batch type dairy waste treatment unit.



COMPLETE OXYGEN DEMAND
1. SKIM MILK = 2340 μL
2. LACTOSE = 1100 μL
3. CASEIN = 1000 μL
OXYGEN CONSUMED-MICRO LITER (μL)
800
600
400
200
1
2
3
NO NUTRIENT
0
2
4
6
TIME-HOURS

Figure 1

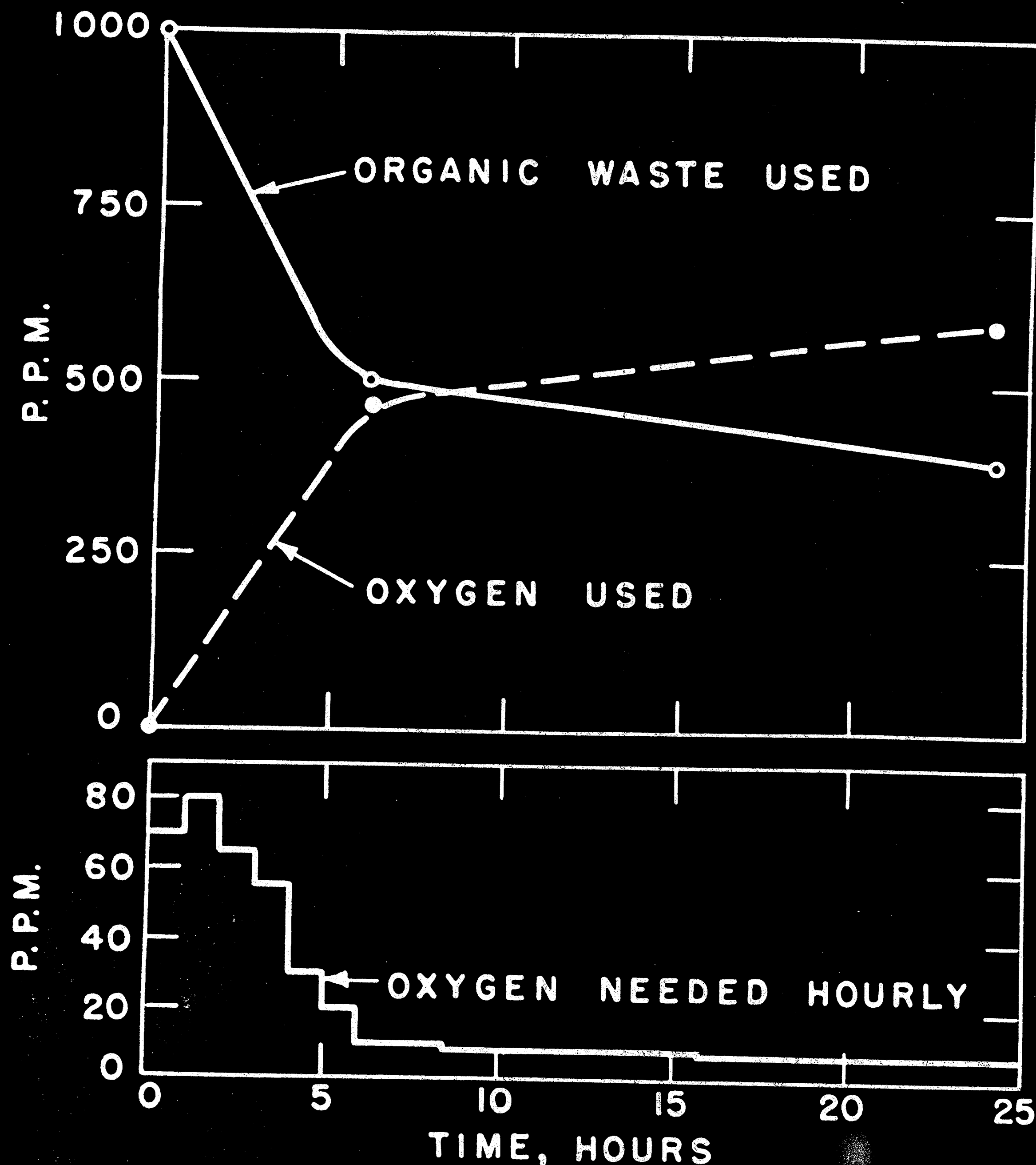

1000
750
500
250
0
P. P. M.
ORGANIC WASTE USED
OXYGEN USED
80
60
40
20
0
P. P. M.
OXYGEN NEEDED HOURLY
0
5
10
15
20
25
TIME, HOURS

Figure 2

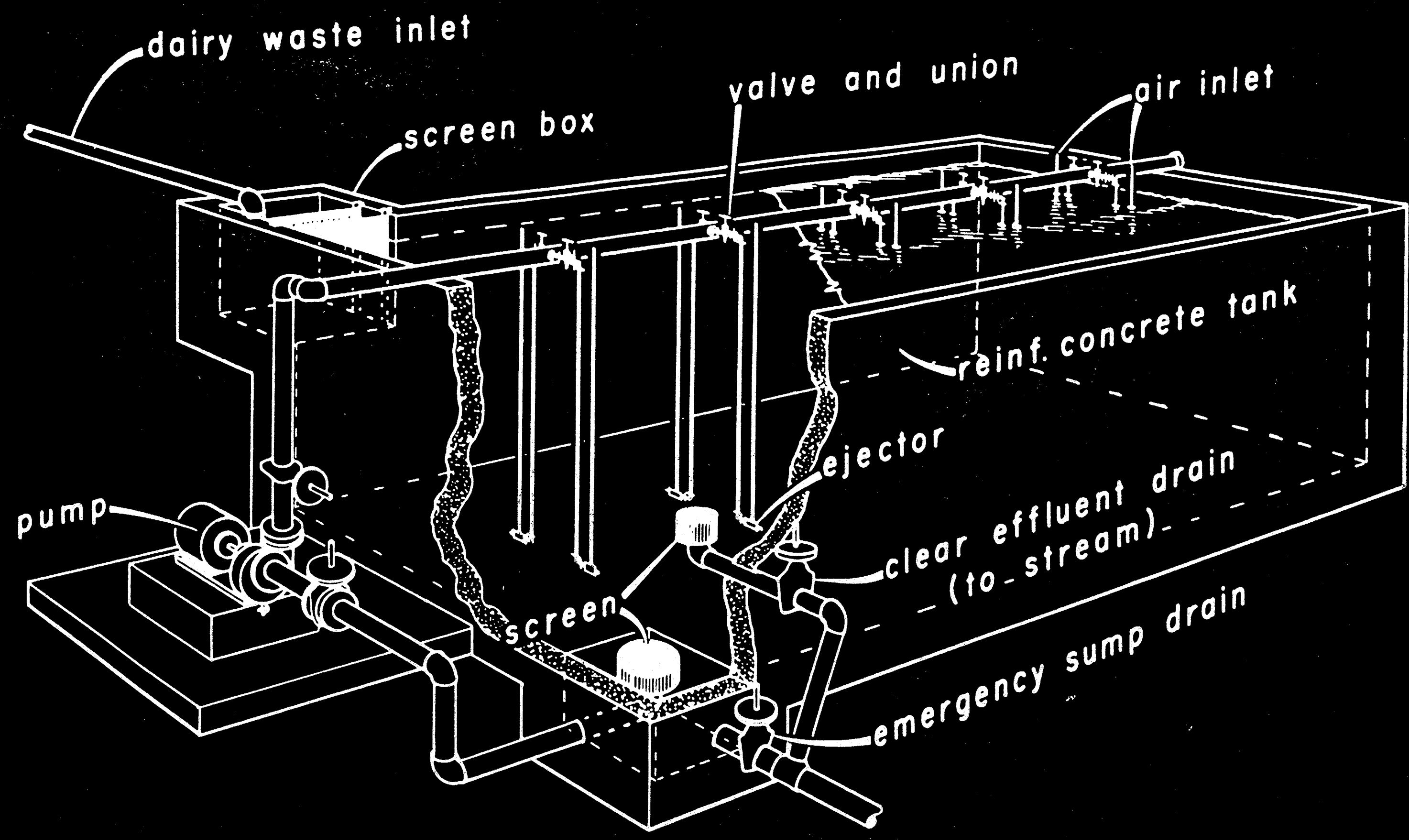

dairy waste inlet
screen box
valve and union
air inlet
reinf. concrete tank
ejector
clear effluent drain
(to stream)
emergency sump drain
screen
pump

Figure 3